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Characterization of briquettes produced from four lignocellulosic material admixtures using a hydraulic briquetting press (HBP)

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ABSTRACT
The physical characteristics and combustion performance of briquettes produced from four lignocellulosic materials and its admixtures using a 5-ton HBP with a rectangular mould had been carried out. The sole materials evaluated include sawdust, waste paper, cow dung and rice barn and its admixtures in the following proportions: Sawdust: paper (2:1), rice barn: paper (2:1), cow dung: paper (2:1), Rice barn: sawdust: paper (1:1:1) investigating the bonding properties of paper. The result shows that due to poor compressibility, sole rice barn produced loosely formed briquettes; sawdust briquettes are weak with low impact resistance and easily disintegrate with hand pressure while paper is highly compressible with, strong and stable briquettes and high impact resistance. Cow dung is poorly drained with low compressibility, but produced stable briquettes with high impact resistance when

dry. Sole sawdust, rice barn and cow dung briquettes have poor combustion performance, burn with considerable amount of smoke and high ash contents. Paper mixed with the sole materials improves the performance of each briquettes resulting in excellent flame propagation, low ash contents, less smoke and good bonding properties, hence is recommended as a binding agent in briquetting.

Keywords: Lignocellulose, hydraulic press, briquettes, admixture, low-density, compressibility,

1. INTRODUCTION

Economic growth, urbanization and growing global population especially in the developing countries of Africa has grossly increased the overdependence on the use of fossil fuels and contributed to the global energy concerns through the increase in global fuel consumption and prices. These problems are largely combated by the springing potential alternative energy banks such as agricultural and wood based residues which are produced in large quantities, but are inefficiently burn in open fields. Apart from the problems of transportation, storage, and handling, the direct burning of this loose biomass in conventional stoves is associated with very low thermal efficiency and widespread air pollution [1].

To overcome these problems, biomass materials can be densified into briquettes and other products to increase its density, durability and heating values. However, these product qualities are depended on several material and product variables. Previous studies have shown that briquette properties strongly depend on material moisture content, particle size, temperature, compacting pressure and feedstock types [2]. For instance, feedstock particles vary in sizes from coarse to fine and powdery, with fine particles adsorbing more moisture than larger coarse particles; hence, undergoing a higher degree of conditioning. Also, grounded coarse materials tend to produce less quality compacts because they are capable of creating natural fissure points that cause cracks and fractures in products [3].

Several studies have equally been reported on the effects of bonding interactions in wood and agricultural materials in densification processes [4, 5, 6]. Bond formation in the densification of wood waste particles requires the knowledge of the uniqueness of the material structure. In all biomass materials, the main bonding components are lignin, with protein and starch being natural binding agents [7]. The softening of these agents heavily depends on the moisture content and temperature of the raw materials [8]. However, temperature being a critical factor in the release of lignin, and protein does not take place at ambient temperatures but at high temperatures, are applicable for high-density extrusion processes are not for ambient temperature processing conditions, which is characteristic of hydraulic briquette press (HBP), hence, binding agents need to be supplied externally. These binding agents can be made of different materials such as starch, paper, etc. which are economically viable.

Controlling material properties and process variables can lead to production of high quality and durable briquettes. This research was carried out to explore the characteristics of some selected wood and agricultural materials densified using hydraulic briquetting press. Several experiments have previously been carried out by many researchers; the results of this study greatly contribute to further improvement of fuel briquette technology.

2. MATERIALS AND METHOD

Feedstock materials and preparation

The dominant lignocellulosic feedstock materials used in this study are sawdust, rice barn, cow dung and waste paper for reasons of their availability, environmental menace and potential uses in waste to wealth conversion process. Sawdust is widely available as mill wastes from sawmilling activities. The rice barn is an exceptional biomass for its good flowability; its ash contains fewer alkaline minerals, thereby having high ash sintering temperature. The materials from different wood species of the tropical rainforest ecosystem and rice barn from various mills were randomly sourced from around Ishiagu mill sites.

Figure 1: Feedstock test materials

Experimental machine description

The hydraulic briquetting machine used for the experiment is shown in Figure 2. The major components of the press include; the frame constructed of angle iron, a 5-ton capacity hydraulic jack, collection tray made of galvanized plate, a square pressure plate and two split-rectangular moulds with locking devices.

Figure 2: (a) Experimental hydraulic press (b) Densification (c) Briquette produced

Working principles of the device: The machine operates on the principle of load-pressure application where compressible materials are subjected to moving force against a stationary surface. The force is exerted by a hydraulic jack, while the plungers compress the material load within the compression chamber. In order to reduce pressure exerted by the jack, the surface area of bearing contact was widened more than the jack extension cap area. Two helical extension springs were attached to the pressure plate to return the hydraulic jack barrel after compression. The springs are connected to the frame and the mould frame by through the hook and loop ends. In operation, the platform and the mould is lifted against the upper plate when the lever is primed. The helical extension springs stretches out as each stroke of jack piston. The stored up energy in the spring forces the platform back on relief of the piston pressure and the formed briquette extracted from the mould. The water drains through the slots made on the mould, through the platform into the receptacle beside the device.

Figure 3: Feedstock materials soaked in water

2.1. Methodology

Particle size distribution: Particle size distribution of sawdust and rice barn materials were determined in the proportions of oversize chips (OS), coarse particle sizes (CPS), pin particle sizes (PPS) and fine particle sizes (FPS) by weight according to standard test procedures reported by [9].

Feedstock materials and preparations

The feedstock materials used in this study include assorted (mixed) sawdust from sawmills, waste papers, rice barn and cow dung. These materials were selected for reasons of its volumetric availability, its uses in waste to wealth conversion processes and combating environmental menace. Each of these materials were sorted for foreign materials and then soaked in different buckets (Figure 3) for few days to increase their particle moisture above 40% and then allowed to drain.

The proportion of material mix: Each material was mixed in the following combination and ratios: Sawdust: paper (2:1), rice barn: paper (2:1), cow dung: paper (2:1), Rice barn: sawdust: paper (1:1:1).

Determination of material density: A 1000 ml capacity measuring cylinder was used to measure a specific volume of the drained material and its weight determined on an electronic weighing scale. The material density is evaluated from the expression:

$$Density = \frac{Weight}{Volume}\left(\frac{kg}{m^3}\right) \qquad (1)$$

Briquetting procedures

The drained materials were fed into the compression mould and primed using the hydraulic jack to compress the material to maximum compression limit offered by the hydraulic jack. The compressed material was left for 5 minutes under load and then pressure relived and the briquette extracted from the mould. The physical properties of the product were then observed and measured, then left to dry in the sun under steady state atmospheric conditions. The physical properties of individual briquette were measured. The mechanical and combustion characteristics of each briquette were determined after drying.

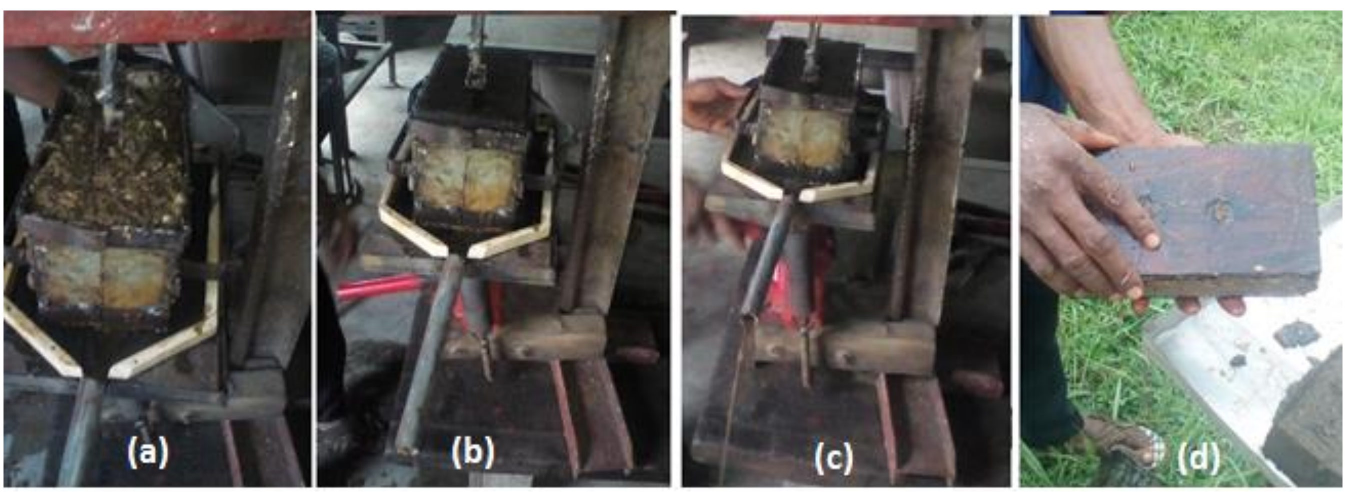

Figure 4: Briquette production using the hydraulic press: (a) material loading, (b) pressure plate inserted, (c) briquette compaction, (d) briquette extraction

Briquette performance tests

Three replicates of each briquette samples were produced and their physical, mechanical and combustion characteristics investigated. The physical characteristics determined include dimensional stability, gravimetric, density and colour, mechanical characteristics include durability and compatibility while combustion characteristics include burning and smoke characteristics.

Determination of briquette physical properties: Three replicates of the briquette samples were produced from rice barn, sawdust and cow dung, paper, and a combination of all in different ratios as mentioned in material preparation. The briquettes produced were weighed after extraction from the mould, its length, width and thickness measured and also when fully dried in the sun.

Determination of briquette density: The bulk density of briquette produced was determined by dividing the mass of the briquettes by their volume.

$$Bulk\ Density = \frac{Mass\ of\ briquette\ produced}{Volume\ of\ briquette\ produced}\left(\frac{kg}{m^3}\right) \qquad (2)$$

Determination of shatter resistance: Dried sample of the briquette were subjected to ten repeated drops from and approximate 1m height from ground surface. The initial weight of the selected briquette was measures as W_1, before dropping, and the final weight measured after shattering W_2. The percentage shattering loss was calculated as:

$$Percentage\ weight\ loss\ (\%) = \frac{W_1 - W_2}{W_1}\ x100 \qquad (3)$$

Shattering resistance (%): The shattering loss was determined by from the expression

$$Shattering\ resistance\ (\%) = 100 - percentage\ weight\ loss \qquad (4)$$

Water absorption rate: Samples of each briquettes were cut into uniform cube sizes of 60mm length, 50mm diameter and the areas of each determined. Each briquettes were weighed and then immersed in 850ml of water in beakers at room temperature. The rate of water absorption was measured at 5 minute intervals and the following properties determined: Percentage gain in weight due to water absorption and resistance to water penetration.

Percentage gain in weight due to water absorption: The percentage gain in weight was calculated from the expression.

$$\%\ M = \frac{M_2 - M_1}{M_1} x100\% \qquad (5)$$

Where

$\%\ M$ = % water gained or absorbed by briquette

M_1 = the initial weight of briquette before immersion and

M_2 = the final weight of briquette after immersion.

Resistance to water penetration: This is evaluated from the following expression.

$$Briquette\ resistance\ (\%) = 100 - \%\ water\ absorbed\ (\%) \qquad (6)$$

Combustion characteristics: The combustion tests were carried out at room temperature conditions in a cook stove to know the quality of briquettes. Briquette sample of known weight was burn and the time taken to completely bur the briquette was monitored using a stopwatch, until the briquettes were completely burnt and ash content was obtained. The burn rate for each briquette sample was computed from the expression:

$$Burn\ rate = \frac{Total\ weight\ of\ the\ burnt\ briquette}{Total\ time\ taken} \qquad (7)$$

3. RESULTS AND DISCUSSION

3.1. Material characteristics

Particle size distribution: Due to the heterogeneous and fluffy nature of the particle sizes of the collected sawdust and rice barn samples, they were classified into four fractional sizes: i.e. oversized, coarse, pin and fine. The particle size distribution rice barn and sawdust are represented by particle distribution curves shown in Figure 5. The curves generally showed similar proportional distribution trend between the two materials regardless of other physical variable factors.

A grading curve of log sieve size against % material passing through the sieve plotted for each samples also (Figure 6) showed similar distribution patterns 100% passing as well as greater percentage of the CPS in rice barn shows.

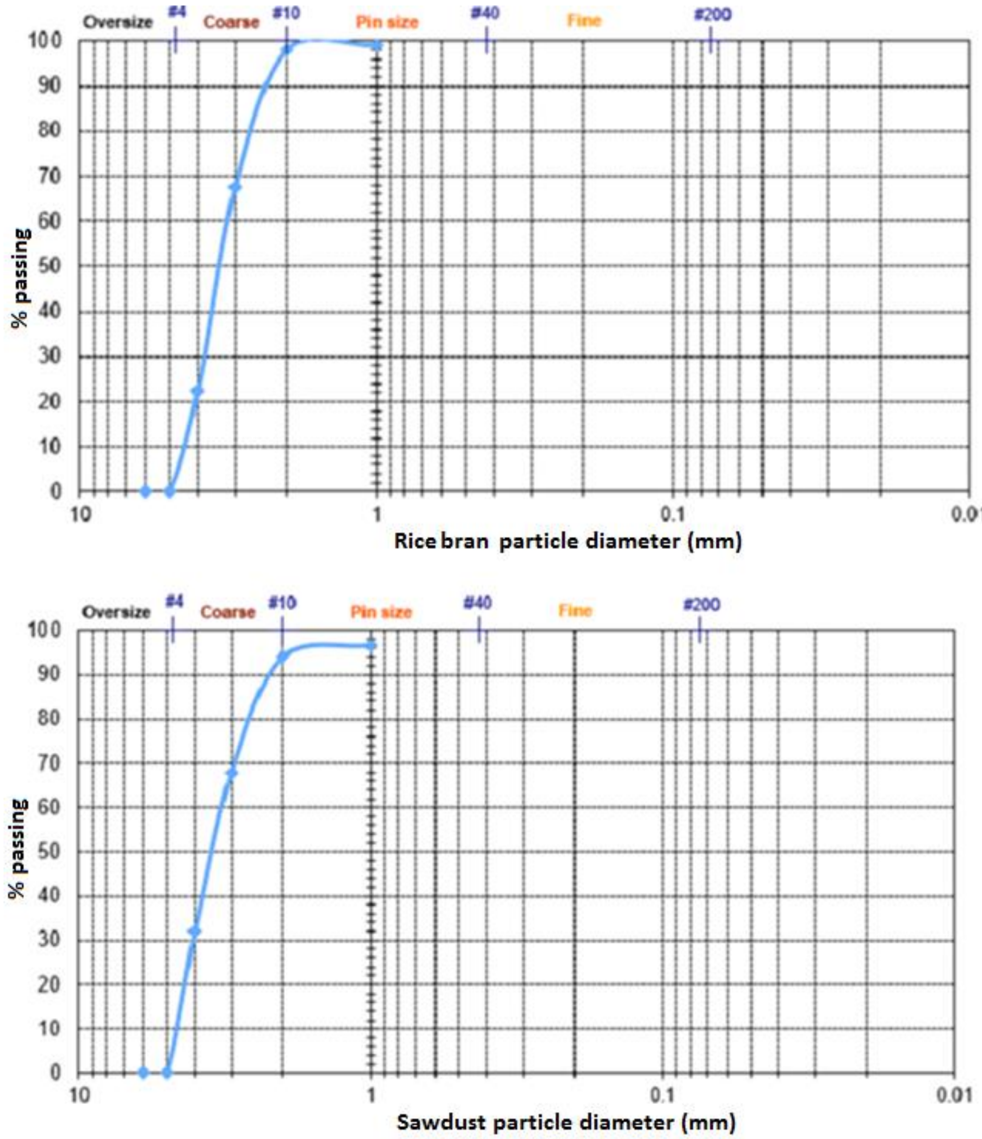

Figure 5: Grain size distribution curve for rice barn and sawdust

Table 1: Densities of material samples

Replicate samples	Beaker mass W_{vs}(g)	Mass (beaker + sample)W_T	Sample mass $W_S(g)$	Volume of sawdust, V_o	Density (g/cm^3)
		Density distribution of sawdust samples			
1		263	98	900	108.89
2		319	154	800	192.5
3	165	333	168	800	210.0
		370	205	800	256.25
Mean					191.91
		Bulk density distribution of rice barn samples			
1		330	80	600	133.33
2	250	340	90	625	144.0
3		320	70	500	140.0
Mean		330	80	575	139.11

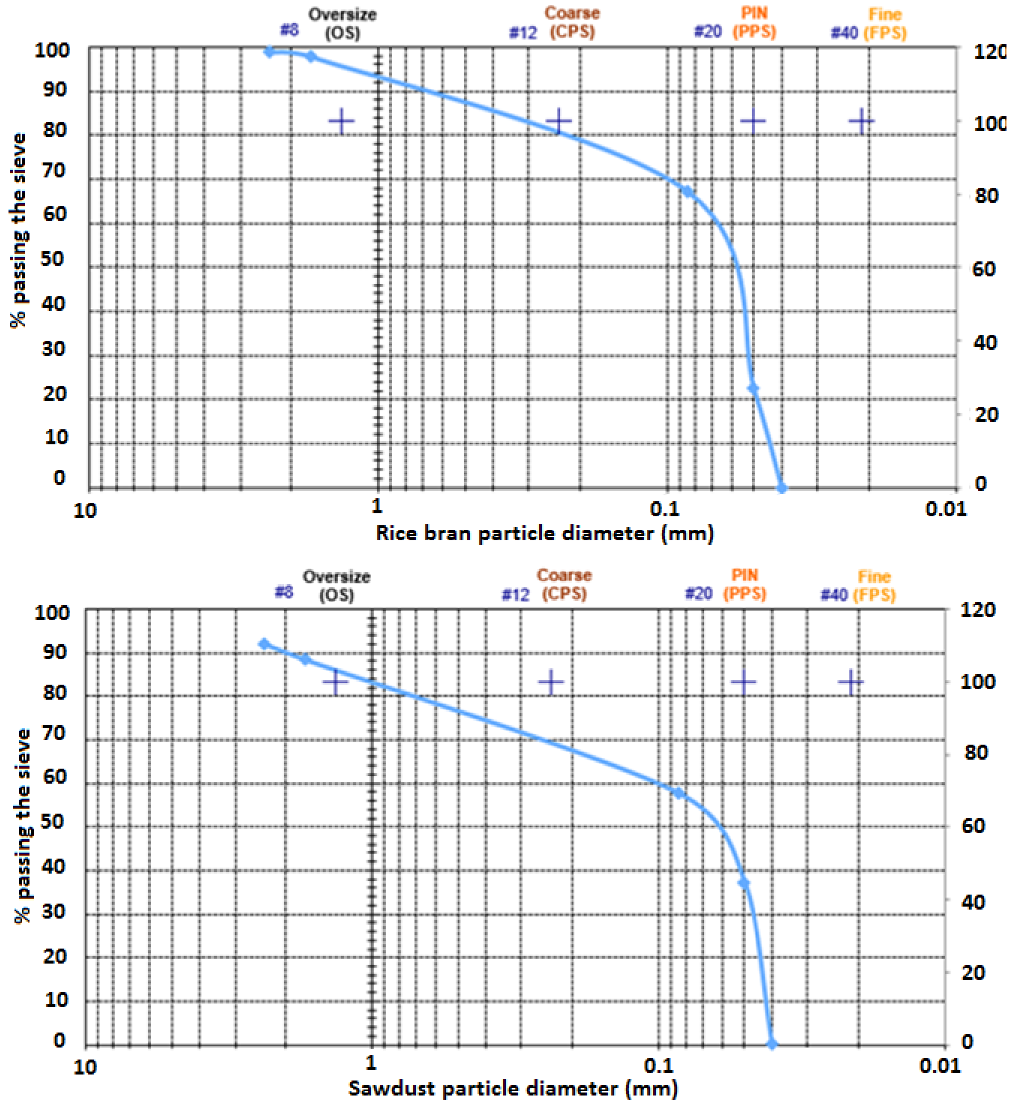

Figure 6: Graph of log sieve size vs % particle passing for rice barn and sawdust

Material particle density: The experimental results of the material particle density determined for sawdust and rice barn samples are shown in Table 1.

From the results, rice barn consistently has high bulk density than sawdust, and a mean bulk density of (191.91 g/cm^3) while sawdust has a mean density of (139.11 g/cm^3). This result is plays significant role briquette formation and the strong effect material particle could have on briquettes produced. Rice barn briquette will have more density than sawdust briquette. Although it has been generally accepted that particle size influences density, this study also shows that material density also influences briquette characteristics.

3.2. Briquette physical properties

Briquette qualities: The briquettes produced from paper, sole sawdust, paper, and cow dungs and admixtures have regular shapes, well-formed, and stable immediately after extraction from mould, however, sole rice barn briquettes are loosely bounded and disintegrated shortly after production. After days of sun-drying, the briquettes produced from paper, sawdust, cow dung and a mixture of the materials became strong as well as those from rice barn.

Briquette dimensional and gravimetric changes: The briquettes produced were examined for changes in dimensions and weight immediately and 30 days after production and the results presented in Table (2). The dimensional changes along the diametric axis

(cleft) and along the axial lengths are measured using a metric rule. There are no significant dimensional changes noticeable in all briquettes produced immediately and after sun drying. However, there are significant changes in weight due to moisture loss.

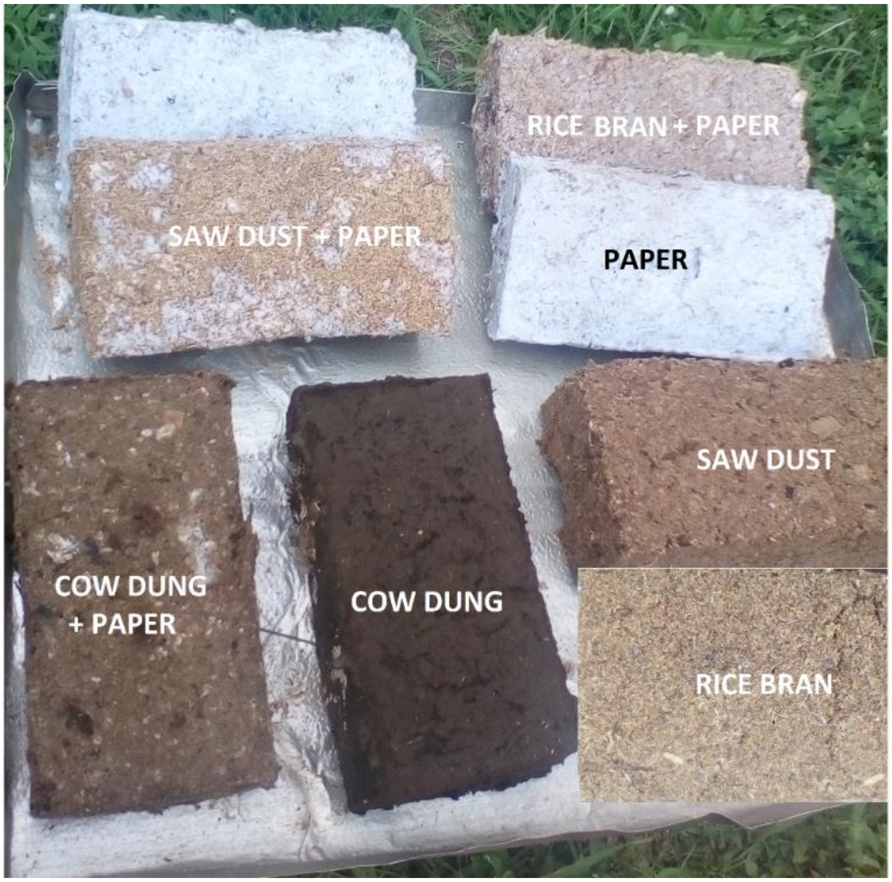

Figure 7: Samples of briquettes produced

Table 2: Dimensional changes in briquette samples before and after drying

Product samples	Weight (g)		Dimensions		
	Moments	30 days	Length (mm)	Breadth (mm)	Thickness (mm)
Sawdust	950	300.00	121.00	110.00	60.00
Paper	850	317.00	196.00	102.00	40.50
Cow dung	1500	400.00	186.00	97.20	46.00
Rice barn	1200	1200	-		
SD:PP	650	300.00	200.00	105.00	50.00
RB:PP	900	400.00	200.00	105.00	60.0
SD:CD:PP	950	350.00	200.00	104.00	45.3

Briquette density: Density of the briquettes were measured in two ways; compressed density(CD); the density measured immediately after extrusion and relaxed density (RD); density measured after a certain length of days in storage (30 days).The summary of the densities of briquette samples were shown in Table 3. Variations in briquette densities after a period of time are as a result of moisture and compressible nature of different materials used. From the results, paper briquettes show high compressibility and hence, higher compressed density. The relaxed density is significantly lower than sole sawdust and rice barn which are lignocellosic materials with high particle densities.

Table 3: Relaxed density (g/cm^3) of briquettes after 30 days of storage

Sample briquettes	Measured weight (g)		Measured volume (mm^3)		Compressed density (kg/m^3)	Relaxed density (kg/m^3)
	Moments	30 days	Moments	30 days		
Sawdust	950	300.00	0.80	1.5	0.63	0.38
Paper	850	317.00	0.81	0.64	1.33	0.39
Cow dung	1500	400.00	1.14	0.83	1.32	0.48
Rice barn	1200	-	1.08	-	1.11	-
SD:PP	650	300.00	1.05	1.05	0.62	0.29
RB:PP	900	400.00	1.26	1.26	0.71	0.52
SD:CD:PP	950	350.00	0.94	0.96	0.99	0.96

Cow dung has the highest relaxed density (0.48$\mathrm{kg/m^3}$), while rice barn with poor compressibility property easily compacts under high particle moisture, with high compressed density, however, after drying, the briquette lost its binding qualities and easily disintegrated, hence has an appreciably low relaxed density. In paper briquettes, particle moisture played a significant role in briquette compressed and relaxed densities with improved particle binding in each of the sawdust and rice barn sole briquettes. Thus, paper can be classified as a natural binder in agreement with [7]. The briquette produced from mixture of paper, cow dung and sawdust produced the highest relaxed density of 0.96 $\mathrm{kg/m^3}$. From these observed characteristics, the quality of the mixed briquettes is better than those of the single material briquettes. The density of the mixed briquettes is higher than those of single materials.

Briquette mechanical characteristics

Briquettes compactibility: Briquettes produced tested for compatibility, that is, the ability of the material to be permanently compressed after the release of pressure. Each briquettes were subjected to moderate hand crushing to test the compactibility. Sole rice barn has the poorest compatibility, being easily disintegrated under slight hand pressure, followed by sole sawdust when compressed without binder. Paper has the best compressibility and compatibility being a refined material with short fiber lengths, then the mixed briquette.

Briquette durability: The following tests were carried out to determine briquette durability.

1) Toughness and impact resistance index (IRI) of briquettes (%): To determine the durability of each briquettes, impact resistance test was carried out by dropping each briquette on hard surface from a 2-meter height to a concrete floor. The number of pieces the briquettes broken into were recorded as shown in Table (4) after 10 repeated dropping.

Table 4: Briquette resistance to gravity and impact at 2-m drop height

Samples	Mean sample weights (g)	Final wt. after 10 drops (g)	Weight loss (g)	% wt. loss	IRI
Sawdust	150.00	51.60	98.40	65.56	52.44
Paper	175.00	174.70	0.8	0.05	218.38
SD:PP	187.00	177.50	9.5	0.05	18.68
RB:PP	168.00	148.52	11.31	0.07	13.13
SD:CD:PP	210.00	203.60	7.00	0.03	29.09

From the tests, it was discovered that for all the briquettes, none completely shattered into pieces with a maximum weight loss of 65.56% for sawdust, and an IRI of 52.44%. The maximum impact resistance index (IRI) of 218.38% was recorded for paper and the least IRI of 13.13% obtained for rice barn and papermix briquette.

2) Briquette water absorption rate (%): The water absorption pattern of each briquette when immersed in 850 ml of clean water at room temperature is shown in Figure8. Paper recorded the highest rate of weight gain (0.33g/sec) absorbing as much as 100g of

water within 5 minutes of immersion and rapidly reached its peak absorption while cow dung (a less porous material) has the lowest weight gain absorbing 0.13g/sec of water at the same time of 5 minutes. Also, from the chart, water absorption rates stabilized for all briquettes after about 15 minutes of immersion in water for paper, sawdust+ paper and rice barn + paper and 40 minutes for cow dung briquettes respectively.

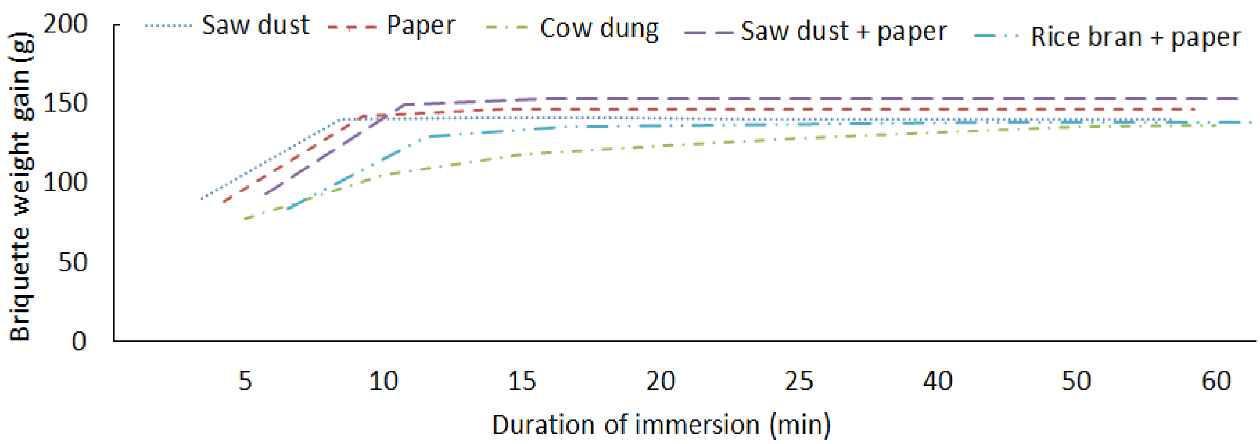

Figure 8: Water absorption rate in different briquette samples

3) Resistance to water penetration (%): The resistance to water penetration was measured by the percentage of water absorbed by briquettes when immersed in water. This was determined when each briquettes were immersed in water for 1hr and the percentage water gain recorded at 5 minute intervals. Figure 9 shows the percentage water gains for each briquette at time intervals. Cow dung briquette has the least percentage of water penetration throughout the experiment, by implication, the highest water resistance by remaining afloat for 15.30 minutes before submerging. This is an indication of low water penetration while paper briquette has the least resistance to water penetration, the briquette remained afloat for only 2.30 minutes while rice barn/paper briquette remained afloat for 3.10 minutes before submerge.

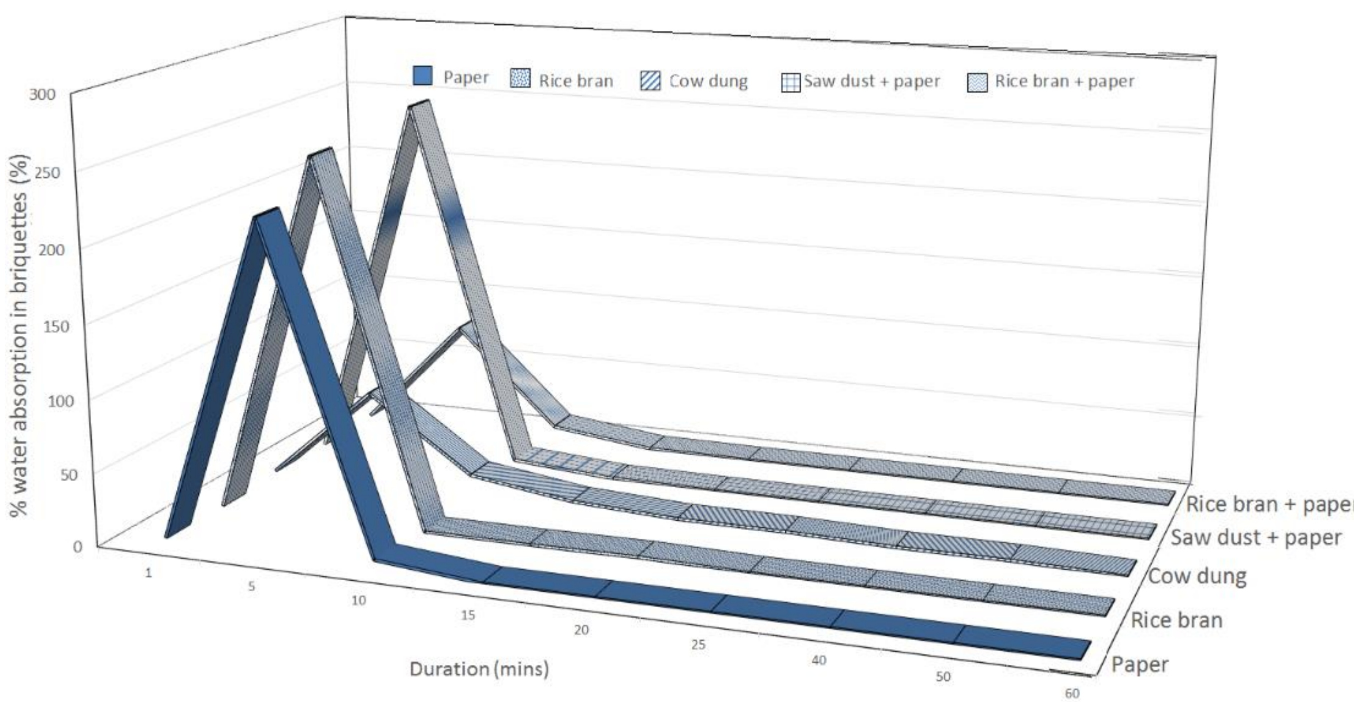

Figure 9: Percentage water absorption rate in different briquette samples

4) Briquette disintegration in water: At the end of one hour of immersion in water, the briquette samples recovered remained undissolved, an indication that all the briquettes produced can withstand some level of water absorption. Then the briquettes were immersed in water undisturbed for 72hr and the water drained, the recovered briquettes retained their shapes and undissolved (Figure 10). This is not a common phenomenon with low and medium-density briquettes; this phenomenon could only be attributed to the impact of compaction mechanism on the products.

Figure 10: Recovered and undissolved briquette samples

Briquette combustion performance

Stove combustion tests were used to test the briquettes' combustion performance. Each briquette was ignited by fire lighter and supplemental fuel (kerosene) enough to initiate burning at the surface of the briquette (Figure 11). Briquette self-ignition time, time required to totally burn off the briquette and the weight of the recovered ash were recorded. The data collected (Table 5) were used to determine the burn rates.

Figure 11: Briquette stove tests: (a) Flame propagation, (b) Burning established (c) Stove with pot stand (d) Water boiling test

Table 5: Briquette combustion performance test

Sample	Weight of sample (g)	Time taken to burn (min)	Weight of sample burnt (g)	Quantity of ash recovered	Burn rate (kg/hr)
Sawdust	300.00	120	103	197	0.15
Rice barn	317.00	115	190	127	0.17
Cow dung	343.00	165	173	170	0.13
Paper	247.00	54	166	81	0.28
Sawdust: paper	247.00	105	183	64	0.12
Rice barn: paper	305.00	109	187	118	0.14

Cow dung: paper	256.00	143	178	78	0.09
Sawdust: cow dung: paper	255.00	128	177	78	0.09

Sole briquette performances: The ignition time for sawdust and rice barn sole briquettes takes an approximate time of 3 minutes, and burns with steady flame. Each briquette retained its shape during burning and did not expand, hence lasts significantly longer compared to their loose feedstock materials, but produced higher quantities of ash. Sole paper briquettes ignite at approximately 2 minutes, burns with good flame propagation and produced less smoke Cow dung briquettes has the least combustion performance evident in poor flame propagation, generate a lot of smokes. Paper has the highest burn rate of 0.28 kg/hr while cow dung has the lowest burn tare of 0.13 kg/hr. By implication, cow dung burns for a longer time and thus better specific fuel consumption rate. A higher quantity of paper briquettes will be required to boil or cook same quantity of food when compared with the quantity of cow dung briquettes required. Sawdust has the highest ash recovery of 197 g burning 300g of briquette while paper has the least ash content recovery of 81g burning an equivalent quantity of briquette. These characteristics are improvements on their loosed material characteristics but not good performances considering the negative environmental impacts they might cause in greenhouse emissions.

Figure 13: Ash recovered per unit weight of briquettes burnt

Composite briquette performances: All the paper composite briquettes of have improved ignition time approximately 2-3 minutes with higher flame propagations than their sole counterparts. The time taken to burn off specific quantity of each briquette determines their burn rates. The total time required for each briquette admixture and the corresponding burn rate factors are comparatively lower than their sole briquette samples. The quantity of ash produced by these products per unit kilogramme of briquette burn are lesser than those of sole briquettes of same unit weight. Observed smoke produced from mixed briquettes during combustion are lesser. The composite characteristics of sawdust, cow dung and rice barn equally showed similar performance trends as the paper composite briquettes with low ash and the least burn rate of 0.09 kg/hr as cow dung/paper briquette. This implies that paper has significant improvements on the performance characteristics of these agricultural materials.

4. CONCLUSION

Based on the overall objectives, the following conclusions are made;

1. Particle size distribution in sawdust and rice barn differ considerably with sawdust having higher percentage proportions of OS and CPS than rice barn. This characteristic improved its performance in briquetting. Rice barn has higher particle density (191.91g/cm^3) than the sawdust (139.11g/cm^3) which made rice barn briquette denser than sawdust of equal volumetric material. This quality affects its compressibility and hence poor performance in briquetting.
2. Ricebarn and cow dung have poor compressibility properties, their briquettes have poor compressed qualities, sawdust briquettes are weak with low impact resistance while paper has good compressibility and high impact resistance. The mixed briquettes have improved characteristics than the sole briquettes.
3. All the briquettes exhibited good resistance to disintegration in water being able to remain undissolved up to 72 hours with cow dung being the best water resistant briquette. The mixture of paper with the feedstock materials improves the quality and binding properties of these materials and hence paper could be taken as a natural binder in low density briquette production.

All briquette admixtures showed improve characteristics than their sole briquettes. Paper mixed with the sole materials improves the performance of each briquettes resulting in excellent flame propagation, low ash contents, less smoke and good bonding properties, hence is recommended as a binding agent in briquetting.

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Conflicts of Interest: The authors declare no conflict of interest.

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